AD-A198 616

DTIC FILE COPY

Time Perception and Evoked Potentials

Paul Fraisse

Université René Descartes

DTIC
SELECTED
AUG 1 8 1988
D

ARI Scientific Coordination Office, London
Milton S. Katz, Chief

Basic Research Laboratory
Michael Kaplan, Director

ari

U. S. Army

Research Institute for the Behavioral and Social Sciences

July 1988

888

U. S. ARMY RESEARCH INSTITUTE

FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the

Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

WM. DARRYL HENDERSON
COL, IN
Commanding

Accesion For		
NTIS CRA&I	✓	
DTIC TAB	☐	
Unannounced	☐	
Justification		
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

ADA198616

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARI Research Note 88-69	2. GOVT ACCESSION NO. - -	3. RECIPIENT'S CATALOG NUMBER -. -.
4. TITLE *(and Subtitle)* TIME PERCEPTION AND EVOKED POTENTIALS		5. TYPE OF REPORT & PERIOD COVERED Final Report September 81 - September 83
		6. PERFORMING ORG. REPORT NUMBER - -
7. AUTHOR(s) Paul Fraisse		8. CONTRACT OR GRANT NUMBER(s) DAJA 37-81-C-0211
9. PERFORMING ORGANIZATION NAME AND ADDRESS Labratoire de Psychologie Experimental Universite Rene Descartes 28 Rue Serpente - 75007 Paris (France)		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q161102B74F
11. CONTROLLING OFFICE NAME AND ADDRESS European Research Office, U.S. Army 223 Old Marylebone Road London NW1 5th England		12. REPORT DATE July 1988
		13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Avenue, Alexandria, VA 22333-5600		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE n/a

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

- -

18. SUPPLEMENTARY NOTES

Michael Kaplan, contracting officer's representative

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Auditory Evoked Potentials,
Durations Reproduction,
Time Perception,

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

> In this research note, time preception is studied from a psychophysical and electrophysiological point of view, during durations reproduction experiments. No relation was found between the auditory evoked potential (AEP) amplitude and durations reproduction errors. The AEP amplitude is influenced, however, by the interval between the clicks and the repitition of the stimulations. The results of the durations reproduction task show an over-estimation of the shorter intervals and an under-estimation of the longer ones.

TIME PERCEPTION AND EVOKED POTENTIALS

by

Paul Fraisse

This Page Intentionally Left Blank

NOTE

SUMMARY

The time perception has been studied in a psychophysical and electrophysiological view in durations reproduction experiments. The durations to be reproduced were presented to human subjects in three conditions : single durations, cadences and rhythmic patterns. During the binaural listening of the stimulations (empty durations delimited by clicks), the auditory evoked potentials (AEP) of the subjects were recorded with vertex and temporal scalp electrodes. The results of the durations reproduction task show an over-estimation of the shorter intervals, and an under-estimation of the longer intervals. The AEP amplitude is influenced by the interval between the clicks and the repetition of the stimulations. We have found no relation between the AEP amplitude and the durations reproduction errors. The long-term variations of these amplitudes may be explained by a modulation of the subject's attention.

The latencies of the different AEP waves tend to decrease with short intervals between the clicks. With rhythmic patterns, an inverse relation between the N1 and P2 latencies and the relative error on the reproduced durations has been found. In the two other experiments, a similar tendency has been retrieved. This relation may be explained by reference to different internal clocks frequencies.

KEYWORDS : Time perception, Auditory evoked potentials, Durations reproduction.

INTRODUCTION.

The perception of time was studied by many authors during the two last centuries, with experiments of estimation and reproduction of time intervals carried upon man and animal. In these studies, subjec:s were asked to estimate if two intervals were equal (estimation task), or to reproduce the intervals that had just been presented (reproduction task). The performances obtained with auditory, visual and somatosensory stimulations were compared (see FRAISSE, 1967). With auditory stimulations, an over-estimation of the short durations and an under-estimation of the long durations were constantly observed (Vierordt's law), and the averages of the responses showed almost no error for intervals about 600-800 milliseconds (ms) : this interval has been named indifference interval. Many interpretations of this phenomenon have been proposed, but in general with a psychological perspective and no final conclusions to this problem have been reached in psychophysics.

A new approach of this problem can be a neurophysiological study of the human behavior during the experiments of time perception. For many years, psychophysiology and neurophysiology experiment upon the electrophysiological signals obtained in response to a stimulation. These "evoked potentials", or "evoked responses", can be recorded on the scalp of the human subject, and are specific of the stimulated sensory channel (auditory, visual or somatosensory evoked potentials). The evoked potentials are constituted by components which are defined by their polarity (positive or negative), their amplitude (expressed in microvolts from the signal baseline or "zero voltage") and their latency from the stimulus onset. Classically, components are separated in "early" and "late" components : the early components, with latencies inferior to 20 milliseconds (ms), correspond to the brainstem activity, and the late components, with latencies superior to 20 ms, correspond to cortical and more diffuse activity (for the auditory-evoked potentials, see BOTTE, 1979). Since their cortical origin, the late components appear more sensitive to stimulation and experimental conditions, or even the subject's attitude. Among the factors which can influence the different late components of the evoked potentials, we can distinguish the stimulation parameters as the intensity of auditory stimuli (BUTLER et al., 1968; PICTON et al., 1974a), the stimulus duration (HUANG, 1981), the stimulation delivery way, monaural or binaural (ALLEN, 1968) or the stimulus probability (FITZGERALD and PICTON, 1981), etc. On the other hand, the direction of the subject's attention (SCHWENT et al., 1976) and the subject's task (WILKINSON and MORLOCK, 1967), for example, have

been found to influence the evoked potentials. The study of evoked responses can so bring information on the subject mental processing, even in neuropathology (LESEVRE, 1982).

Our purpose was to study the auditory evoked potentials (AEP) recorded in durations reproduction experiments and to compare them with the reproduction performances of the subjects. We employed "empty durations" : the durations presented to the subject are delimited by clicks which are all physically identical. In this way, the difference between stimulations lies in the interval between clicks which can be comprehended as a difference of "stimulation rate" in physiological sense. The AEP results must be interpreted with reference to this stimulation rate influence as well as the variations of the subject's attention in the different experimental situations.

The influence of stimulus repetition rate on auditory evoked potentials has been universally observed : in all these studies, the principal result is that inter-stimulus intervals (ISIs) shorter than 10 seconds produce decreased evoked responses. This influence of the stimulation rate has been found on early AEP components at the level of the cochlear nucleus, the inferior colliculus and the median geniculate corpus of the non-anesthetized cat (WEBSTER, 1971), but with very short ISIs: from 10 ms to 1 second. On the same preparation, HORVATH (1969) did find that the major factor which influenced the AEP amplitude was the variability of the successive single responses, and that this variability began to increase when the stimulation rate was increased to 1 or 2 stimuli per second. In human, DAVIS et al. (1966) found that the AEP late components amplitude was not modified by the stimulus repetition when the ISIs were superior to 10 seconds, and in this case the AEP amplitude was equal to the maximal amplitude obtained with single auditory stimuli. With shorter intervals, they found that "if the intervals are regular the average amplitude is about 1/2 maximal at 3 sec, 1/4 at 1 sec and 1/6 at 0.5 sec. If pairs of tone pips are employed the amplitude of the second response depends on the long interval between pairs as well as on the short interval between the members of the pairs". The late components latencies did not vary with the interval between the tone pips. RITTER, VAUGHAN and COSTA (1968) studied the evolution of the AEP along series of stimulation with different ISIs. With 2 sec interval, the N1-P2 amplitude was stabilized at 50 % of the first response before the fourth stimulus; with 10 sec interval the N1-P2 amplitudes did not decrease across stimuli of each serie, but slightly for successive runs (as with 2 sec intervals). "The rapid drop for the faster rate of stimulation was considered to have only the appearance of habituation, and was viewed as reflecting refractoriness within the auditory system". BUTLER (1973) found that "the N1-P2 components of the auditory evoked response was reduced in amplitude as the presentation rate of the stimuli was increased from 1/4 sec to 10/sec. Further increases in repetition rate reversed this trend". The response latencies appeared reduced when the test stimulus was preceded by intervening stimuli : "this was interpreted to mean that the intervening stimuli "alerted" the auditory nervous system to the impending arrival of the test stimulus".

Some authors have considered the subject's attitude in similar ex-

periments. ROTH et al. (1976) employed 50 ms tone pips with 0.75, 1.5 and 3 sec intervals. When the subject's task was to count soft tones, the P2 amplitude was increased with attention, and N1 and P2 were later. The evoked responses following 3 sec intervals showed greater N1 amplitudes than with 1.5 sec intervals. The P2 amplitude was larger after the 3 sec than after the 1.5 sec interval, and smaller after the 0.75 sec than after the 1.5 sec interval. The N1 and P2 latencies were minimal with 1.5 sec interval. SCHWENT, HILLYARD and GALAMBOS (1976) employed pip tones of different frequencies (1500 and 800 Hz) presented respectively to the left and the right ear. The subject had to respond by pressing a pushbutton when he detected a different tone (1575 or 860 Hz) in the channel selected by the experimenter, and to ignore all stimuli in the other ear. Three ISI conditions were studied : short (200-500 ms, mean = 350 ms), medium (400-1520 ms, mean = 960 ms) and long ISIs (800-3040 ms, mean = 1920 ms). With short ISIs, they noticed an increase of N1 amplitude when the subjects did attend the stimuli. With longer ISIs, this "attention effect" showed a marked reduction. The target stimuli did evoke potentials with a large positive wave (P3) which was not influenced by the stimulation rate. We can see here that in some cases, the effects of the attention and the stimulation rate on the AEP may appear contradictory : the AEP appear reduced when the interval between the stimuli is short, but in this case the attentive subject's attitude may produce an increase of the AEP amplitude, as when the interstimulus interval is longer the AEP amplitude is quite maximal, and the subject's attention produces no effect.

In our durations reproduction experiments, the AEP were recorded at the moment the subject listened to the durations to be reproduced. In all cases, the subject had to reproduce intervals (empty durations) by pressing a key, and the reproduction would occur after the end of the stimulation, in order not to interfere with the sensory evoked potentials. We have wanted to study the AEP as the subject has to reproduce the duration between two brief stimulations. We did want to relate the possible AEP modifications with the errors in the durations reproductions. We have wanted to study these relations particularly in 3 cases : a) when an interval is isolated; b) when it is repeated successively (cadences); c) when the intervals produce rhythmic patterns. We make the hypothesis that the conditions variation should modify the relations between the AEP and the psychophysical reproductions.

I. EXPERIMENTS.

The intervals to be reproduced were presented to the subjects in three different conditions :

1. single intervals of 150, 300, 600, 1200 or 2400 ms, which the subjects had to reproduce after the end of each stimulation;

2. series of 8 successive equal intervals of 300, 600, 900 or 1200 ms ("cadences"); the subjects had to reproduce only one inter-

val after the end of each serie;

3. rhythmic patterns constituted by a 300 and a 600 ms interval ("iamb" = 300 then 600 ms interval; "trochee" = 600 then 300 interval), each pattern being presented four times in a stimulation sequence, with a "neutral" interval of 1200 ms between the patterns; the subjects had to reproduce one rhythmic pattern (iamb or trochee) after the end of the sequence, that is to say the two successive intervals which constitute the pattern.

The definitions of "cadences" (= series of equal intervals) and "rhythms" (= different intervals grouped in patterns) are peculiar to P. FRAISSE. All the intervals were separated by clicks that the subjects heard binaurally. In the three experiments, the subjects could habituate to the experimental set and the stimulations sequences before the beginning of the experimentation. No information about his performance was given to subjects during the experimentation. In general, they reported that the task was difficult, especially for shorter intervals, but could not appreciate whether they over- or under-estimated the intervals.

The AEP are obtained by summation of the electrophysiological signals recorded in response to the stimulations. A such single response is constituted by the true evoked response superposed to the background EEG activity. The summation (and the averaging) of the evoked responses increases the signal-to-noise ratio between the evoked response and the background activity, and reduces the little variations observed from response to response. In our experiments, the AEP were summed in relation with the stimuli constituted by clicks. The electrophysiological signals were recorded when the stimulations were presented to the subjects. By this way, we have recorded the AEP obtained during the stimulations presentations, and the durations reproduced by the subject after these same presentations.

II. EXPERIMENTAL EQUIPMENT.

The experiments have been realized upon an experimental set using an APPLE II micro-computer, which had been programmed to provide the different stimulation sequences and to measure the subjects responses (the reproduced intervals measurements were recorded on diskettes for a later treatment). The EEG signals acquisition was made upon a Z80 ZILOG or a second APPLE II microcomputer. In the first case (single durations experiment), the micro-computer did sum in real time a pre-defined number of signals selected trial-by-trial. In the cadences and rhythmic patterns experiments, the APPLE II was utilized to digitalize continuous EEG epochs (during 82 seconds, which is the maximal number of data that can be stored in the APPLE II central memory), to save them on a disk-

ette, and to sum the evoked potentials in delayed time. The treatment
of the AEP consisted of (eventually) the summation, the digital filter-
ing using the Fourier transform, the measurement of the amplitudes and
latencies, and the tracing of the obtained AEP on paper.

1. Stimulation sequences.

In the first experiment (reproduction of single intervals), the
APPLE II was programmed to produce on its speaker pairs of clicks separ-
ated by a silent interval. The clicks were amplified and delivered bi-
naurally to the subject by a Melodium type 234 or Pioneer SE-30A head-
phone. The peak intensity of the clicks was 90 dB, and their duration
almost equal to 10 ms. The different intervals were given in a
pseudo-random order, and during a sequence of approximately 40-50 trials
the AEP corresponding to one of the durations to be reproduced were
summed by the Z80 ZILOG microcomputer.

In the experiments concerning the cadences and the rhythmic pat·
terns, the intervals were generated by assembling language procedure
and the clicks were then picked up at an input-ouput connector of the
APPLE II. These clicks are shorter than in the first experiment (dura-
tion = 1 ms), but they were delivered to the subjects in the same
manner. As in these experiments a second APPLE II was used to digital-
ize the EEG signals by continuous epochs of 82 seconds, the experimenta-
tion was pursued by sequences of stimulation during approximately 82
seconds. We did record 12 blocks of 82 seconds in the cadences repro-
duction experiment, and 8 blocks in the rhythms reproduction experiment.

2. Reproduced durations measurement.

In all cases, the subjects had to reproduce the durations that he
had just heard by pressing a key that he kept in the hand. The measure-
ments of these intervals were realized with an intervalmeter based upon
a MOTOROLA 6840 Programmable Timer Module and mounted on an extension
card of the APPLE II. By this way, the micro-computer recorded the re-
production measurement with a code number corresponding to the repro-
duced duration. In our experiment, the durations were measured with an
absolute precision of 0.1 ms. The measurements which showed a too large
error (due to some error of manipulation) were discarded. We then cal-
culated the averages of the reproduced durations, their
standard-deviations, the differences between the reproductions averages
and the true durations (absolute error, and relative error expressed as
a percent of the true duration), and the variability of the responses
(expressed by the percent of the standard-deviation reported to the true
durations). The calculation formulas are :

absolute error = (mean of reproduced durations) - stimulus duration

$$\text{relative error} = \frac{\text{absolute error}}{\text{stimulus duration}} \times 100$$

$$\text{variability} = \frac{\text{reproduced durations standard-deviation}}{\text{stimulus duration}} \times 100$$

3. Electrophysiological recordings.

The electrophysiological recordings were realized with 1 cm silver cup electrodes fixated at Cz, left and right temporal areas (T3 and T4, after JASPER, 1958) with bentonite paste. The signals collected by bipolar montages, Cz to left temporal area and Cz to right temporal area, were amplified by an ECEM E1-3G amplifier, with a time constant of 0.3 seconds and a filter set to 50 Hz; the ground reference was fixated on the forehead of the subject. In the experiments with cadences and rhythmic patterns, only left temporal electrodes were used. The electrophysiological signals were sampled at the rate of 200 Hz (one point every 5 ms).

In the first series of experiments (with single intervals), the amplified EEG signals were summed in real-time by a ZILOG micro-computer. One summation was realized at a time, and the different summations were saved on a diskette of the ZILOG system then transferred to the APPLE II for later treatment. Each AEP obtained corresponded to 20 signals summed from the instant of the first clicks of the pairs, except the standard AEP obtained with 40 single clicks at the beginning of the experimental session.

For the cadences and rhythmic patterns experiments, we used a second APPLE II microcomputer to digitalize the EEG signals. In this case, the raw electrophysiological recordings correspond to 82 seconds of continuous EEG, with the stimulations marks, saved on a diskette. Each face of the diskettes can hold 4 blocks of 82 seconds. The summations were realized in delayed time upon the raw recordings, in respect with the stimulation marks, and the signals were summed from 100 ms before the stimulations : this 100 ms period was used to calculate the baseline of the evoked potentials. The AEP summation epoch was, in all cases, 1.28 second. The AEP were summed after been selected by the experimenter : this allows us to reject the artefacts as eye movements. After summation, the AEP were traced on paper and saved on diskettes.

4. Experimental procedures.

The experimentation was carried out on 7 subjects in the first experiment (4 females and 3 males, aged from 19 to 50), and 8 (4 females and 4 males, aged from 20 to 36) in the two other experiments. Subjects sat in an armchair placed in a small and dark room, and held the key in one hand. They were asked to keep their eyes open, to stare at a light mark straight ahead, to blink and move their eyes as little as possible, and not to count or speak during the stimulations or the reproduction of durations. The attention of the subjects was focused on the precision of the responses, no quickness being required. First of all the electrodes were placed on the scalp, then the subject was trained to press the key in order to reproduce the durations. After each recording period the subjects were told to relax.

The half of the subjects who were tested in the cadences and rhythmic patterns began with the cadences reproduction task; the other half out of them began with the rhythmic patterns reproduction task. In general, the both experiments took place on the same day.

III. RESULTS OF THE SINGLE INTERVALS EXPERIMENT.

1. Durations reproductions.

The first experiment, concerning the single intervals, was carried out on 7 subjects whose results are shown in the arrays above. These results were obtained with 50-60 trials for each duration, presented in pseudo-random order (among these 50-60 trials, we summed the AEP corresponding to only 20 trials).

Table 1 : Mean reproduced durations (in ms) in the single
intervals experiment.

Durations	300 ms	600 ms	1200 ms	2400 ms
Mean reproduced durations :				
C.B.	439.96	596.41	1044.83	2108.71
J.B.	383.2	584.69	1106.4	1937.45
N.B.	382.92	614.8	1216.46	2096.24
N.G.	410.54	620.24	1065.85	1561.1
M.L.	390.65	644.9	1227.71	2154.3
H.C.	439.4	811.14	1548.27	2072.36
R.B.	397.03	646.65	1131.99	1952.52
Average	406.24	645.55	1191.64	1983.24
Standard-dev.	24.69	76.51	171.90	202.88

Table 2 : Relative errors upon single intervals reproductions,
expressed in percent of the stimulus duration.

Durations	300 ms	600 ms	1200 ms	2400 ms
Relative err.				
C.B.	46.65	-0.6	-12.93	-12.14
J.B.	27.73	-2.55	-7.82	-19.27
N.B.	27.64	2.47	1.37	-12.66
N.G.	30.42	-2.53	-5.81	-34.95
M.L.	30.22	7.48	2.31	-10.24
H.C.	41.48	35.19	29.02	-13.65
R.B.	32.34	7.77	-5.67	-18.35
Average	33.78	6.75	.07	-17.32
Standard-dev.	7.36	13.26	13.81	8.44

Table 3 : Variability of the single intervals reproductions.

Durations	300 ms	600 ms	1200 ms	2400 ms
Variability				
C.B.	26.97	18.72	18.62	13.78
J.B.	11.36	14.06	17.75	8.6
N.B.	22.72	18.13	15.43	12.71
N.G.	26.15	28.64	25.26	36.79
M.L.	21.38	17.34	17.26	18.61
H.C.	17.44	21.39	14.75	14.55
R.B.	17.34	22.2	15.11	10.63
Average	20.48	20.07	17.74	16.53
Standard-dev.	5.51	4.63	3.62	9.47

The results show that relative errors decrease as the durations to be reproduced increase : we retrieve there the preliminary assomption concerning the over-estimation of the short durations (300 ms) and the under-estimation of the long durations (2400 ms). We can notice the little relative errors obtained with 600 and 1200 ms intervals. The reproductions of 150 ms intervals were not taken in account because for many subjects this interval appeared too much brief to be really reproduced : the subjects attempted to produce the shorter intervals that could, without anymore reproduce the same interval they just heard. The responses variabilities show a decrease as the durations increase, as precedently found, and the strong variability observed with 150 ms reproductions shows clearly that motor limitations interfere with the time estimation and the reproduction task in case of very short durations. For the longer interval (2400 ms), subjects reported that it was difficult to reproduce it, and we can notice that they all under-estimated this duration.

2. Evoked potentials.

In our results we have accepted the identification of the AEP components proposed by PICTON et al. (1974). These components characteristics are their polarity and their latency. There is two positive components, named P1 (latency about 55 ms) and P2 (lat. = 170 ms), and two negative ones, named N1 (lat. = 100 ms) and N2 (lat. = 280 ms) (cf. fig. 1).
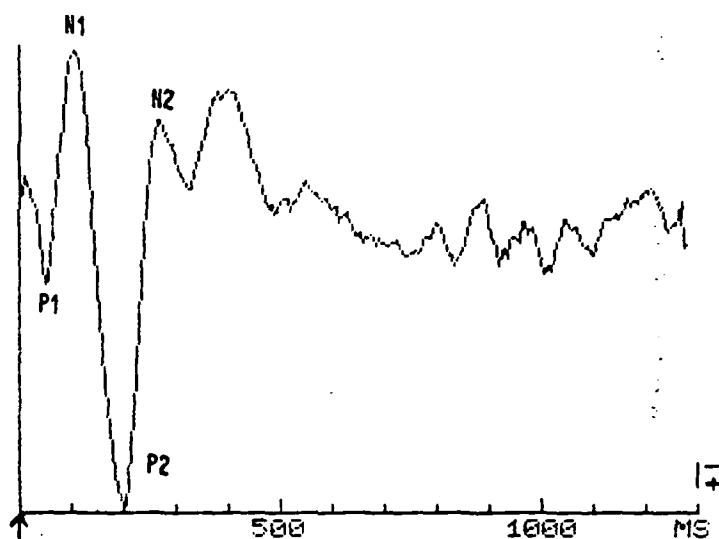
Fig. 1 : standard AEP obtained by averaging on
40 signals, in response to single clicks. For all
the AEP tracings negativity is upward, and the
little vertical mark in the right bottom corner
corresponds to a 2 μV amplitude. Stimulations are
indicated by vertical arrows along the time scale.
Times are in milliseconds (ms).

The amplitudes of the different components are measured peak-to-peak and correspond to the Pl-Nl, Nl-P2 and P2-N2 segments. These amplitudes are calculated from the two AEP obtained with the pairs of clicks, then the amplitudes of the second AEP components are expressed as a percent of the corresponding first AEP component. We have obtained the following ratios (Table 4) :

Table 4 : Relative amplitudes of the second AEP (in % of the first AEP amplitude) obtained in the single intervals experiment.

Relative amplitudes	Durations (ms)			
	300	600	1200	2400
amplitude P1-N1	55.93	54.46	75.82	64.78
amplitude N1-P2	62.44	69.18	92.77	87.45
amplitude P2-N2	47.02	81.41	103.2	95.73

We can notice that the Pl-Nl relative amplitudes are constantly smaller than the two others, and vary much less than the other relative amplitudes. The Nl-P2 and P2-N2 relative amplitudes increase as the durations increase; a similar tendency has been found for the Pl-Nl relative amplitudes. The Nl-P2 and P2-N2 relative amplitudes of the second AEP are maximal for 1200 ms : the Nl-P2 amplitude of the second AEP is larger than the first AEP after a 1200 ms interval. For the 2400 ms interval, we have found that the second AEP is smaller than the first one : it is possible that it may be due to an artefact in the methods of amplitudes measurement, but we can relate that to the difficulty to reproduce this interval which has been reported by all the subjects. In this case, and parallelly with the general under-estimation of the 2400 ms interval, one may wonder if the subjects did really reproduce exactly this interval, or if they reproduced a reasonably "long" interval which was in reality shorter than the stimulation interval.

The AEP obtained with 150 ms intervals have not been measured, for the two AEP do merge and one cannot define the components of the first AEP from those of the second one (cf fig. 2). We may recall here that the 150 ms interval was very difficult to reproduce for all the subjects, essentially due to motor limitation. It seems that this limitation may be sensory too : the subjects can hardly "perceive" this 150 ms duration, and on the other hand they can hardly "produce" a 150 ms interval. In this case, the reproduction of this 150 ms interval appears very difficult, and we do observe for this interval excessively
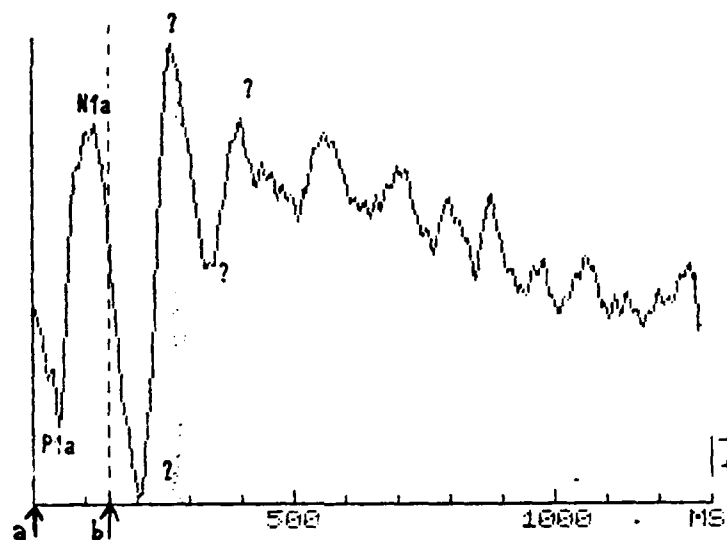
long reproductions and merging AEP.

Fig. 2 : single 150 ms interval AEP (20 signals
averaged). Clicks are indicated by arrows a and
b, and the AEP waves are named Pla, Nla, etc. We
can notice that the second evoked response is so
much reduced that there is few differences with
the standard AEP (fig. 1).

It must be noticed that the 150 and the 2400 ms intervals appeared dif-
ficult to reproduce to the subjects : the first one is too short to be
precisely reproduced, and the second one is too long to be correctly
perceived. We found specific characteristics in the AEP corresponding
to these intervals : for 150 ms, the two successive evoked responses
could hardly be separated, and for 2400 ms we noticed an inversion of
the amplitudes evolution which tend to increase with longer intervals.
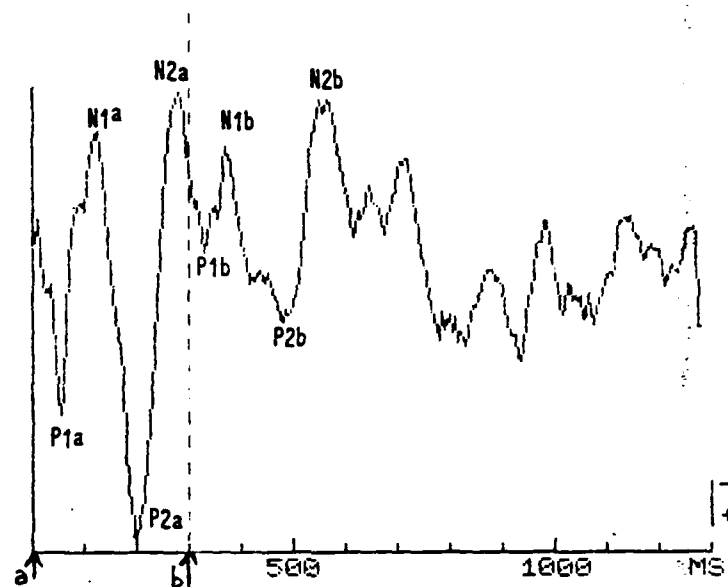
Fig. 3 : single 300 ms interval AEP. Clicks are indicated by arrows.

In general, the second AEP appears superimposed to a large and slow negative wave, which may be retrieved in AEP obtained with longer intervals. This wave, similar to a classical contingent negative variation (CNV), appears also after the first AEP when the interval between the clicks is sufficiently long. It seems that this CNV, in case of 150 ms interval, is generated only by the first click, and that the second response is inhibited (cf fig. 3, 4, 5 and 6).
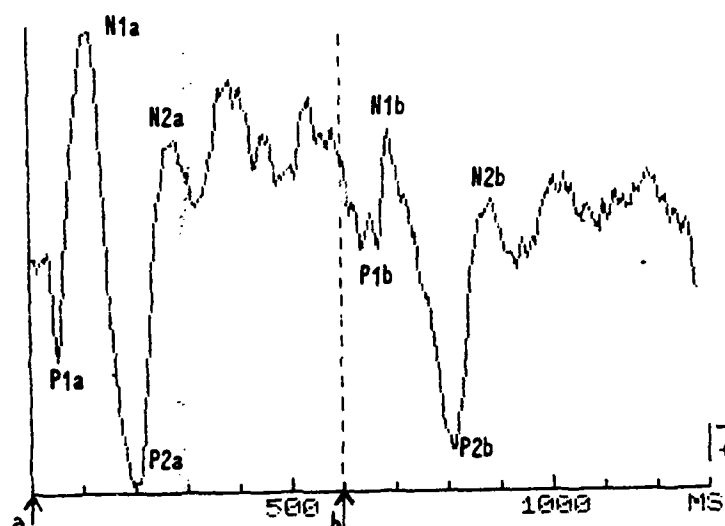
Fig. 4 : single 600 ms interval AEP. Clicks are indicated by arrows. The second AEP appears clearly with the same shape than the first AEP, but with a reduced amplitude. This amplitude reduction is less important than with a 300 ms interval (see fig. 3).
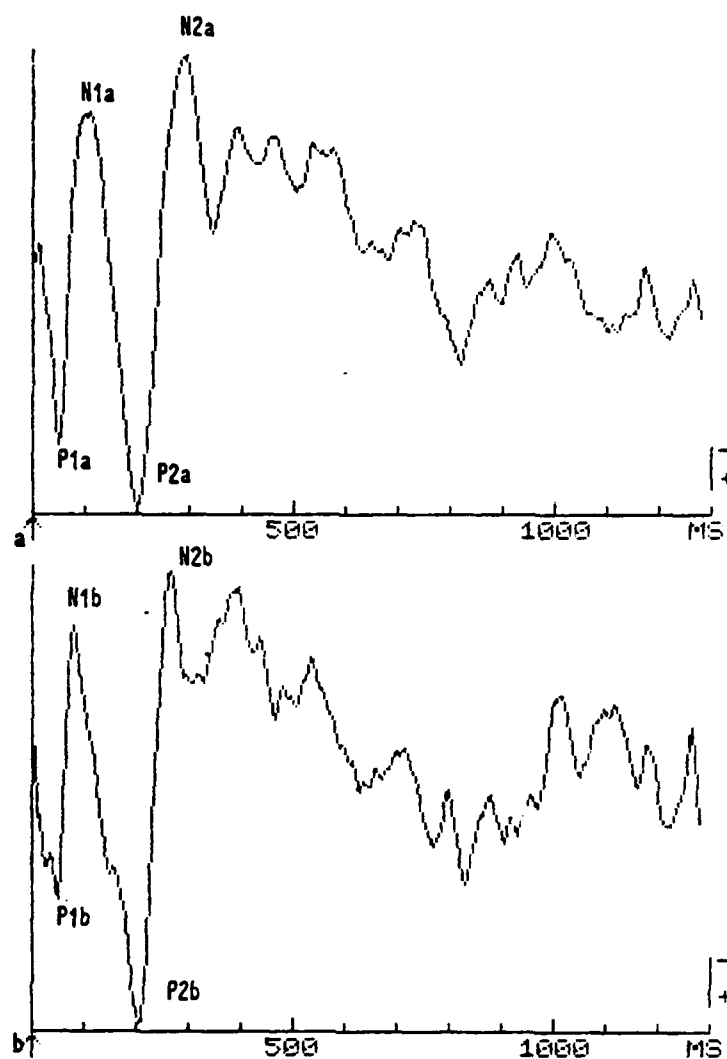
Fig. 5 (top) and 6 (bottom) : single 1200 ms interval AEP (first AEP top, second AEP below, the both traced with the same scale). We can notice that the second AEP has quite the same amplitude than the first AEP.

For latencies, we have found that the latencies of the second AEP components vary as much as the corresponding latencies of the first AEP, and this for all the durations experimented (apart 150 ms). We have found no clear relation between the latencies of the second AEP and the relative errors at the same intervals, but it seems that the latencies of N1 and P2 in the first AEP are related with the average performance for the different subjects. A similar result has been presented by PICTON and HILLYARD (1974) : they noticed an increase of the N1 and P2 AEP components when the attention of the subject was directed toward the corresponding stimulus. The P3 component, which is classicaly present in stimulus detection experiment, has not been retrieved in our experiment : in the subject tasks, all the stimuli must be taken in account, they are all physically identical and easily perceived, and the time interval between the clicks is the only pertinent characteristics which may vary. So, the factors producing a P3 component (detection of target stimuli, unpredictability of stimuli, etc.) are not involved in our experiments.

3. Relations between psychophysical and electrophysiolﾃgical data.

We notice a relation between the mean relative errors of the reproduced durations and the relative amplitudes of the second AEP : these two kinds of results are related to the interval between the clicks. If we consider the individual results, this relation appears not significative. So, the psychophysical and electrophysiological results are influenced by the interval between the clicks, but are not related to each other : the both effects of the interstimulus interval on the reproduction performance and the AEP amplitudes appear independant in this experiment.

An other way to examine these results is to consider the results of the subjects with extreme reproduction performances. In this case, the subject H.C. can be selected as the more over-estimating the durations, and the subjects J.B. and N.G. as the more under-estimating. If we do compare the AEP obtained with these subjects in this experiment, we can notice that H.C. shows AEP with longer N1 and P2 latencies than J.B. and N.G.; for J.B. and N.G. the second AEP is followed by a slow negative wave which we did not retrieve for H.C.. We found no major difference in the AEP relative amplitudes obtained with these subjects.

IV. RESULTS OF THE CADENCES EXPERIMENT.

1. Durations reproductions.

The following arrays give the responses of the 7 subjects who reproduced the cadences. Two other subjects performed this experiment,

but they have been set apart because their AEP showed great perturbations. These results correspond to the relative errors, expressed in percent of the durations to be reproduced. Each stimulation sequence was presented 25-30 times to subjects.

Table 5 : Mean reproduced durations (in ms) in the cadences experiment.

Durations	300 ms	600 ms	900 ms	1200 ms
Mean reproduced durations :				
B.L.	312.45	603.31	762.48	957.15
M.L.	353.48	594.12	898.41	1074.03
F.M.	317.31	564.2	849.14	1093.09
N.G.	320.82	600.39	770.49	952.05
F.P.	306.44	534	683.27	775.76
C.B.	397.66	576.18	761.42	955.84
M.B.	427.73	607.78	879.67	1138.11
Average	347.98	582.85	800.7	992.29
Standard-dev.	47.48	26.63	77.28	121.91

Table 6 : Relative errors of the reproduced durations in the cadences experiment.

Durations	300 ms	600 ms	900 ms	1200 ms
Relative err.:				
B.L.	4.15	0.55	-15.28	-20.24
M.L.	17.83	-0.98	-0.18	-10.5
F.M.	5.77	-5.97	-5.65	-8.91
N.G.	6.94	0.065	-14.39	-20.66
F.P.	2.15	-11.0	-24.08	-35.35
C.B.	32.55	-3.97	-15.4	-20.35
M.B.	42.58	1.3	-2.26	-5.16
Average	16	-2.86	-11.03	-17.31
Standard-dev.	15.83	4.44	8.59	10.16

Table 7 : Variability of the reproduced intervals in the cadences
experiment.

Durations	300 ms	600 ms	900 ms	1200 ms
Variability				
B.L.	7.98	16.43	7.29	10.18
M.L.	14.47	6.67	9.97	7.34
F.M.	11.5	5.87	7.71	5.99
N.G.	16.85	18.86	10.97	12.93
F.P.	11.8	7.05	11.95	10.92
C.B.	11.47	6.13	5.37	5.73
M.B.	22.3	13.52	11.15	9.81
Average	13.77	10.65	9.2	8.99
Standard-dev.	4.67	5.49	2.44	2.7

In this experiment, the indifference interval (corresponding to
zero mean error, and calculated by linear regression) is 645 ms. This
value is shorter than the one found in the precedent experiment, as the
absolute errors obtained with 300, 600 and 1200 ms appear also smaller.
These differences may be due to the repetition of the durations to be
reproduced, which are presented eight times consecutively before the
subject reproduce them, but also to a range of durations different than
in the first experiment. In the first experiment the durations range
from 150 to 2400 ms, and in this one they range from 300 to 1200 ms.
The influence of the durations range has been explained by a "central
tendency" that leads the subjects to compare the different presented du-
rations to an average and to over-estimate the shorter durations and to
under-estimate the longer durations (FRAISSE, 1948).

The variabilities of the reproduced durations, though obtained with
less trials then in the first experiment, are smaller than in the simple
intervals reproduction task. The difference between these two results
seems to be due to the repetitive presentation of the durations in the
second experiment. We can notice a tendency to smaller variabilities
with longer intervals, but this variation is not significative in this
case.

2. Evoked potentials.

For these experiments we have measured separately the amplitudes of
the N1 and P2 components, for the nine AEP obtained with each cadence.
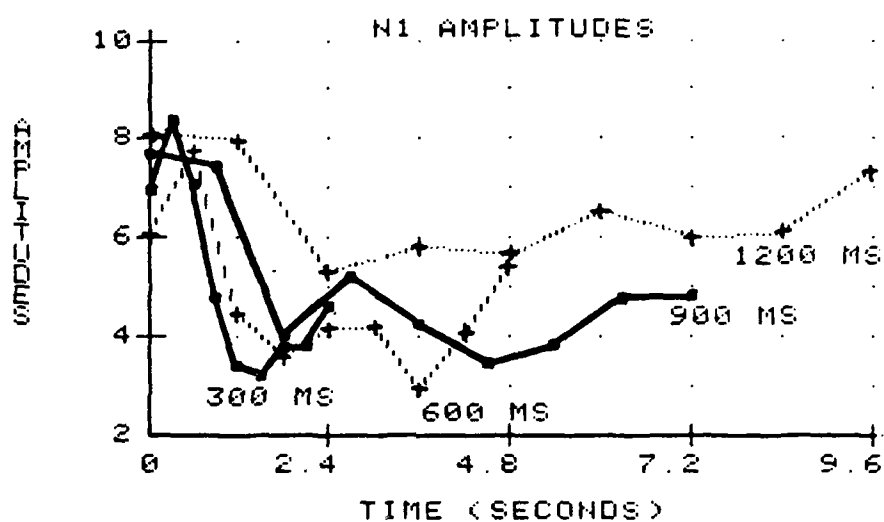The mean N1 and P2 amplitudes obtained upon 7 subjects are presented in

fig. 7 and 8.

Fig. 7 : mean amplitudes (in µV) of the N1 component of the AEP obtained in the cadences experiment. Each curve represents the mean N1 amplitudes of the 9 AEP of stimulation sequences. We can notice that for the 300 and 600 ms cadences, the second AEP N1 amplitude is increased in regard with the first AEP of the sequence.
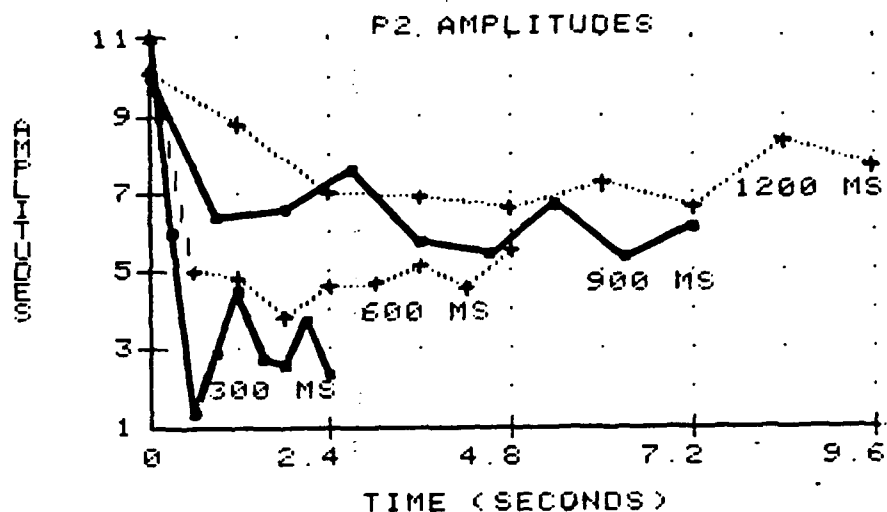
Fig. 8 : mean amplitude (in µV) of the P2 compo-
nent of the AEP obtained in the cadences experi-
ment. We did not retrieve the amplitude increase
for the 300 and 600 ms cadences second AEP, as
found with the N1 amplitudes (fig. 7). Apart
this difference, the curves are similar to those
of the figure 7.

We can notice "U shaped" curves: for the first AEP, the N1 and P2 amplitudes decrease, then increase softly. With the Wilcoxon test, significant differences are found between the first and the second AEP P2 amplitudes only for 300 and 600 ms cadences, whereas N1 remains constant or a little larger for 300 and 600 ms cadences. This difference may be explained by a slow negative wave which is superposed to the N1 and P2 components of the second AEP of the stimulation sequence when the interval between the two first clicks is sufficiently short (inferior to 900 ms in our case). With longer intervals, the second AEP begins after the end of this slow wave. If we consider that this slow component is similar to a contingent negative variation (CNV), this would mean that the first interval of the stimulation sequence did serve to the subject to determine which interval will be to reproduce, as there is only 4 different interval values to reproduce. It is of some interest to recall that, in this experiment, the indifference interval has been found equal to 645 ms, that-is-to-say inferior to 900 ms interval with which we did notice no negative slow wave.

The increase of the N1 and P2 amplitudes for the last AEP of the series has not been found to be statistically significant, but is present in the four curves. The initial decrease of the N1 and P2 amplitudes can be explained by the repetition of the stimulations. As precedently found by many authors, the decrease of the amplitudes depends upon the interval between the clicks, and the amplitudes are stabilized before the fourth click (RITTER et al., 1968). The slight increase of the N1 and P2 amplitudes at the end of the stimulation sequence was not yet described in literature (except by WASTELL and KLEINMAN, 1980, for visual evoked potentials but using similar intervals than us) : we can interpret this effect with a variation of the attention level of the subjects, who had to reproduce the duration just after the end of the stimulation sequence. Along the stimulation sequences, the AEP amplitude decreases with the clicks repetition, then the subject's attention begins to grow up as the end of the sequence comes near, and consequently the AEP amplitude tends to increase.
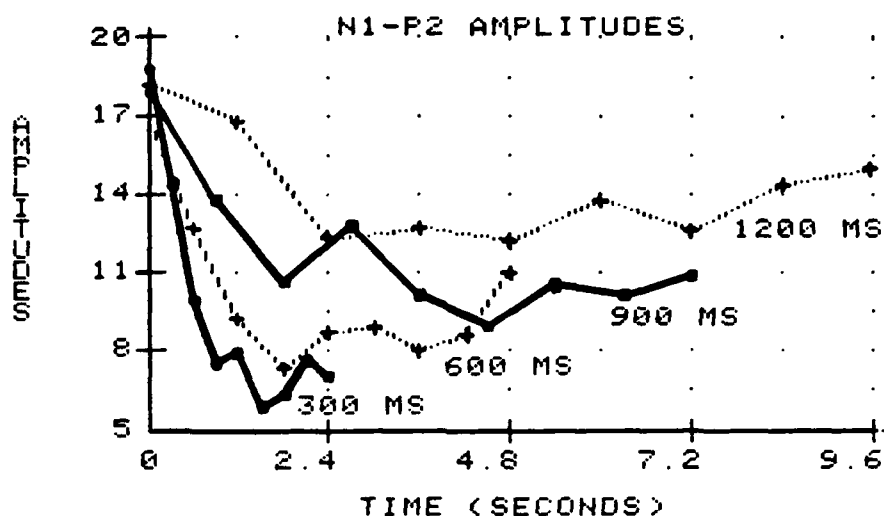
Fig. 9 : mean N1-P2 amplitudes (in μV) of the
AEP obtained in the cadences experiment.

If we consider the N1-P2 amplitudes, we do obtain more separate
curves with a quite similar shape. We found a significant difference
between the minima of the curves and the 9th AEP only for 600 and 1200
ms cadences (see Table 8 and fig. 9).

Table 8 : Mean N1-P2 amplitudes (in microvolts) obtained upon
7 subjects in the cadences experiment, for the 9 successive
AEP of each stimulation sequence.

Serial number of the AEP	300 ms	600 ms	900 ms	1200 ms
1	18.78	16.97	17.88	18.19
2	14.37	12.74	13.84	16.74
3	9.87	9.23	10.57	12.26
4	7.68	7.36	12.8	12.65
5	7.91	8.75	10.14	12.2
6	5.94	8.91	8.91	13.78
7	6.39	8.05	10.53	12.55
8	7.62	8.58	10.08	14.41
9	7	10.98	10.91	14.99

The curves of the N1-P2 amplitudes along the stimulation sequences
appear coherent with the preceeding interpretation. As we did consider
now the differences N1-P2, it may explain that some little superfluous
variations are suppressed and that the N1-P2 amplitudes curves are more
regular.

For the latencies of N1 and P2, we noticed a slight but not signi-
ficant tendency to a decrease with stimuli repetition. For the 7 sub-
jects, the mean latencies measured upon the different cadences have been
found a little longer with the shorter intervals (300 ms): this effect
seems more pronounced for the N1 wave (Tables 9 and 10).

Table 9 : Mean latencies (in ms) of the N1 component for the
9 AEP of the stimulation sequences.

Serial number of the AEP	300 ms	600 ms	900 ms	1200 ms
1	94.29	94.29	98.57	91.43
2	102.14	93.57	87.86	88.57
3	109.29	91.43	86.43	90.71
4	89.29	89.29	83.57	80.71
5	94.29	87.14	88.57	87.14
6	105.71	89.29	90.71	84.29
7	89.29	88.57	84.29	84.29
8	95	87.86	75.71	81.43
9	93.57	92.14	94.29	84.29
Averages	96.99	90.4	87.78	85.87

Table 10 : Mean latencies (ms) of the P2 component for the
9 AEP of the stimulation sequences.

Serial number of the AEP	300 ms	600 ms	900 ms	1200 ms
1	165	161.43	175	165.71
2	187.86	166.43	147.86	160.71
3	180	150.71	146.43	157.14
4	152.86	148.57	154.29	146.43
5	156.43	134.57	149.29	147.14
6	164.29	140.71	148.57	155.71
7	134.29	145	152.86	157.14
8	152.86	141.43	142.86	152.86
9	142.14	154.29	157.86	159.29
Averages	159.53	149.24	152.78	155.79

3. Relations between the psychophysical and electrophysiological data.

As in the precedent experiment, the decrease of the AEP amplitudes
and the relative errors of the reproduced durations are related to the
interval between the clicks, but there is no significative relation
between them.

We selected the more under-estimating subject (F.P.), and the more over-estimating subject (M.B.), in order to obtain some more interindividual differences. These differences lead in this case only upon the P2 amplitude : for M.B. we have noticed a less important decrease of the P2 amplitude along the stimulation sequence with 900 and 1200 ms intervals. But the N1-P2 peak-to-peak amplitudes along the stimulations sequences show no great difference between these two subjects, and the N1 and P2 latencies are quite identical for F.P. and M.B..

V. RESULTS OF RHYTHMIC PATTERNS EXPERIMENT.

1. Durations reproductions.

For the reproduced rhythmic patterns, we have calculated the relative error of the two durations (300 and 600 ms). Each pattern was reproduced about 28 times. The arrays above give the results obtained with 8 subjects. Six of them have served as subjects for the cadence reproduction experiment.

Table 11 : Mean reproduced durations (in ms) in the rhythmic patterns experiment.

Rhythmic pat. +++ Intervals	IAMB +++++			TROCHEE +++++++++		
	300 ms	:	600 ms	600 ms	:	300 ms
Mean reproduced durations :						
B.L.	291.63	:	590.5	521.92	:	297.43
M.L.	309.15	:	633.66	636.69	:	316.9
N.M.	331.07	:	612.03	535.12	:	310.69
M.E.	367.02	:	688.29	658.38	:	360.19
N.G.	342.32	:	752.41	773.99	:	366.92
F.P.	279.77	:	485.78	489	:	269.13
C.B.	339.12	:	568.3	696.5	:	347.89
M.B.	309.9	:	526.15	578.48	:	314.77
Average	321.25	:	607.14	611.26	:	322.99
Standard-dev.	28.85	:	85.76	97.41	:	33.26

Table 12 : Relative errors of the reproduced rhythmic patterns.

Rhythmic pat. +++	IAMB +++++		TROCHEE ++++++++	
Intervals	300 ms :	600 ms	600 ms :	300 ms
Relative err.	:			:	
B.L.	-2.77 :	-1.58	-13.01 :	-0.86
M.L.	3.05 :	5.61	6.11 :	5.63
N.M.	10.36 :	2.01	-10.81 :	3.56
M.E.	22.34 :	14.71	9.73 :	20.06
N.G.	14.11 :	25.4	29.0 :	22.3
F.P.	-6.74 :	-19.04	-18.5 :	-10.29
C.B.	13.04 :	-5.28	16.08 :	15.96
M.B.	3.3 :	-12.31	-3.59 :	4.92
Average	7.09 :	1.19	1.88 :	7.66
Standard-dev.	9.62 :	14.29	16.23 :	11.09

Table 13 : Variability of the reproduced rhythmic patterns.

Rhythmic pat. +++	IAMB +++++		TROCHEE ++++++++	
Intervals	300 ms :	600 ms	600 ms :	300 ms
Variability	:			:	
B.L.	4.46 :	5	6.28 :	3.92
M.L.	8.32 :	6.75	11.16 :	6.54
N.M.	10.76 :	12	8.12 :	5.35
M.E.	11.12 :	7.84	6.33 :	7.95
N.G.	20.93 :	20.3	18.42 :	23.11
F.P.	10.39 :	11.83	13.26 :	8.17
C.B.	7.44 :	6.56	10.55 :	6.71
M.B.	5.05 :	6.16	8.98 :	6.88
Average	9.81 :	9.56	10.38 :	8.58
Standard-dev.	5.15 :	5.05	4.03 :	6.03

The relative errors about 300 ms intervals are very small, compared to the ones observed in the two first experiments. For the 600 ms interval, the relative error is smaller than in the first experiment, but

a little more important than in the cadences experiment. We can notice a slight tendency to larger over-estimation of the durations with the trochee. The variability of the reproductions of the 300 ms intervals is smaller than in the two first experiments, whereas the variability for 600 ms is of the same order than in the cadences reproduction experiment. We have also studied the total durations of the reproduced rhythmic patterns (the duration of each presented pattern is 300 + 600 = 900 ms) (Table 14).

Table 14 : Relative errors and variability of the reproductions
of the whole rhythmic patterns duration.

| Rhythmic pat. | IAMB | | TROCHEE | |
+++	relative error	: variability	relative error	: variability
Subjects		:		:
B.L.	-1.98	: 4.05	-8.96	: 4.47
M.L.	4.76	: 5.11	5.95	: 7.24
N.M.	4.79	: 10.07	-6.02	: 6.58
M.E.	17.26	: 5.51	13.18	: 5.35
N.G.	21.64	: 14.68	27.68	: 16.75
F.P.	-14.51	: 9.2	-13.09	: 12.1
M.B.	-7.11	: 4.95	-.75	: 7.59
C.B.	.82	: 4.43	16.04	: 6.98
Average	3.21	: 7.25	4.25	: 8.38
Standard-dev.	11.92	: 3.74	14.02	: 4.06

We can notice that the 900 ms interval, which corresponds to the whole duration of each rhythmic pattern (300 + 600 ms), is reproduced with over-estimation, compared with the two precedent experiments. This over-estimation reflects probably the influence of the constitution of the 900 ms interval in a rhythmic pattern : in fact, we cannot reasonably assimilate one whole rhythmic pattern to the 900 ms interval of the cadences reproduction experiment.

2. Evoked potentials.

In this experiment, our first study was to sum all the responses obtained for the four rhythmic patterns of each series and for all the

trials. By this way the AEP were summed on 80 signals, and correspond
to 100 ms before the first click of the patterns and to the whole pat-
terns (iamb or trochee). On each AEP we can distinguish the three res-
ponses to the three clicks of each pattern (cf fig. 10 and 11).
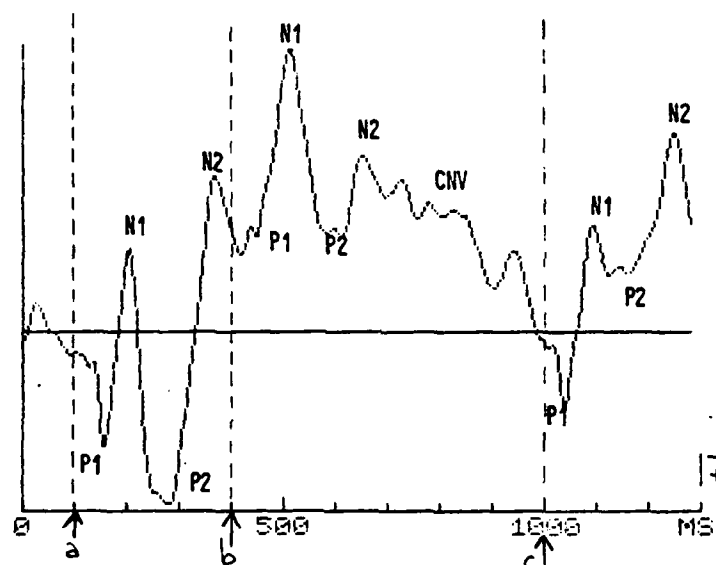
Fig. 10 : AEP obtained with a rhythmic pattern
stimulation (Iamb), averaged upon 80 signals.
Clicks are marked by the arrows a,b,c.
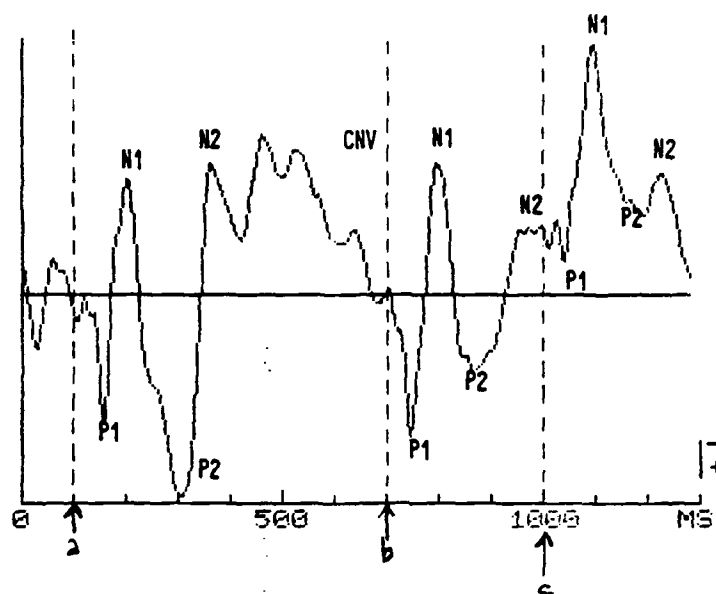
Fig. 11 : AEP obtained with a rhythmic pattern
stimulation (Trochee), averaged upon 80 signals.
Clicks are marked by the arrows a,b,c.

We can notice that for the iamb (fig. 10) the second AEP appears
"shifted upward" by a slow negative wave which tends to decrease when
the third click of the pattern arrives (900 ms after the first click).
For the trochee (fig. 11) the first AEP is followed by a quite similar
negative wave which is almost terminated when the second click of the
pattern arrives (600 ms after the first click). Another slow wave seems
to begin after this second AEP. This wave may be a CNV as precedently
found in the cadences experiment.

We summed then separately the AEP corresponding to the successive
rhythmic patterns. By this way, we obtained 4 signals for the two
rhythmic patterns employed in our experiment. Each signal includes 3
AEP, obtained in response to the 3 clicks of the patterns. The ampli-
tudes are given in Table 15 (fig. 12).
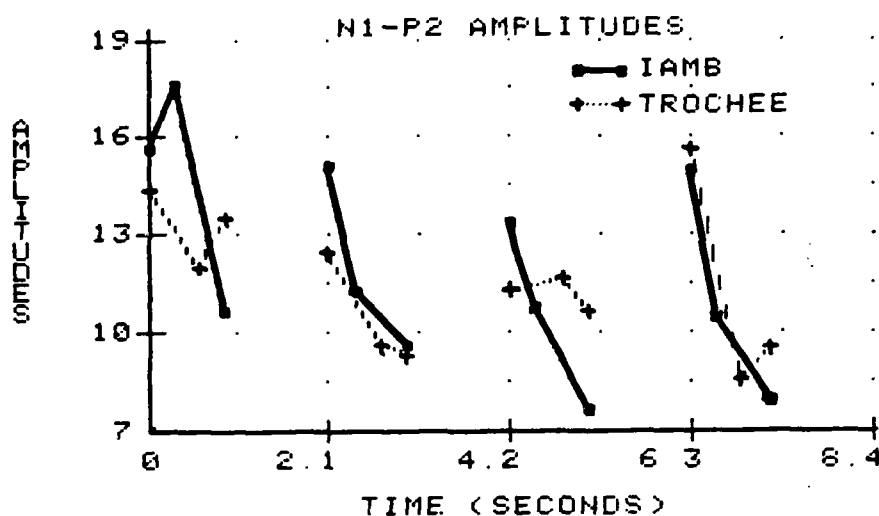
Fig. 12 : mean N1-P2 amplitudes (in μV) of the
AEP obtained in the rhythms experiment. The four
successive patterns are separated, for the iamb
and the trochee. We can notice the amplitude in-
crease between the end of a pattern and the begin-
ning of the following pattern.

Table 15 : Mean N1-P2 amplitudes (microvolts) of the 3 AEP for
the 4 successive patterns of the stimulation sequences
(8 subjects).

Serial number of pattern	IAMB			TROCHEE		
	1st AEP	2nd AEP	3rd AEP	1st AEP	2nd AEP	3rd AEP
1	15.62	17.57	10.64	14.34	11.95	13.44
2	15.03	11.28	9.62	12.48	9.56	9.26
3	13.28	10.78	7.56	11.26	11.64	10.63
4	14.99	10.47	7.91	15.65	8.51	9.48

We may notice that the third AEP of the different patterns is more
decreased in case of the iamb, after a 600 ms interval, than in case of
trochee, after a 300 ms interval. In the first pattern of the sequence
(iamb or troche), the 300 ms interval is followed by an increase of the
N1-P2 mean amplitude, and the 600 ms interval by a decrease : this ef-
fect is exactly the inverse of what has been found in the two other ex-
periments. If we consider the N1-P2 amplitudes of the second AEP rela-
tively to the first AEP, and of the third AEP relatively to the second,
we find a similar tendency for the mean N1-P2 amplitudes calculated upon
the four rhythmic patterns. The ratio of the second AEP to the first
one is 84.64 % for the iamb (interval = 300 ms) and 79.41 % for the tro-
chee (interval = 600 ms), and the ratio of the third AEP to the second
one is 72.88 % for the iamb (interval = 600 ms) and 103.01 % for the
trochee (interval = 300 ms). These results show that the 600 ms inter-
val is more inhibiting than the 300 ms interval, but when it arrives in
first place (trochee) the N1-P2 amplitudes appear less decreased than in
the case of the iamb.
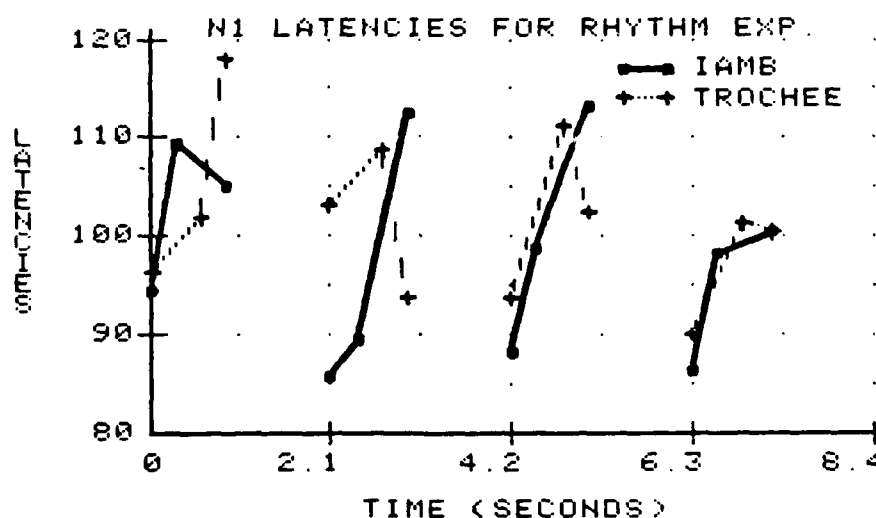
Fig. 13 · mean N1 latencies (in ms) of the AEP
obtained in the rhythms experiment. The curves
show an increase during the patterns, and a decre-
ase between two successive patterns.
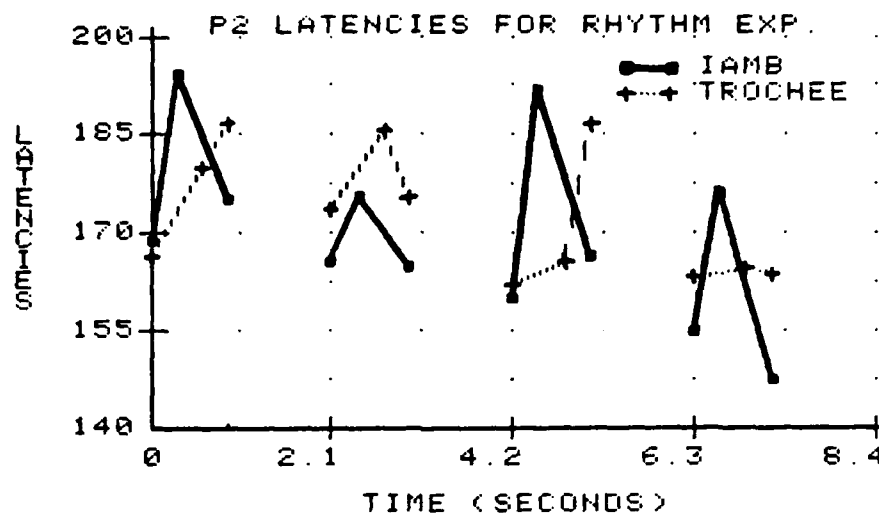
Fig. 14 : mean P2 latencies (in ms) of the AEP obtained in the rhythms experiment. The latencies tend to reduce along the stimulation sequence, and are less increased between two patterns than for the N1 latencies (figure 13).

The N1 and P2 latencies of the second AEP of the successive patterns increase in the case of the both rhythmic patterns (Tables 16 and 17, and fig. 13 and 14). The P2 latencies of the third AEP are smaller than those of the second AEP in the case of iamb (after 600 ms from the precedent stimulus), but longer in the case of trochee (after 300 ms from the precedent stimulus). For the N1 latencies of the third AEP, we found an inverse evolution : shorter latencies with the trochee and longer ones with the iamb. We can notice than the presentation order of the 300 and 600 ms intervals influences the N1 and P2 components : after a 300 ms interval the N1 latencies are longer when this interval is presented firstly (iamb) than when it is in second position (trochee), and the P2 latencies are longer after a 600 ms interval when this interval is presented firstly (trochee) than in second position (iamb). This effect can be related as a "first position effect", by which after the first interval of the rhythmic pattern the latencies tend to increase. In addition, this effect may add up to a tendancy to increase the latencies after short intervals, in this case more after the 300 ms interval than after the 600 ms interval.

Table 16 : Mean latencies (in ms) of the N1 component of the 3 AEP
for each of the 4 patterns of the stimulation sequences,
for the iamb (left) and the trochee (right).

Serial number of pattern	IAMB			TROCHEE		
	1st AEP	2nd AEP	3rd AEP	1st AEP	2nd AEP	3rd AEP
1	94.4	109.4	105	96.3	101.9	118.1
2	85.7	89.4	112.5	103.1	108.8	93.8
3	88.1	98.8	113.1	93.8	111.3	102.5
4	86.3	98.1	100.6	90	101.3	100.6
Average	88.6	98.9	107.8	95.8	105.8	103.8

Table 17 : Mean latencies (in ms) of the P2 component of the 3 AEP
for each of the 4 patterns of the stimulation sequences,
for the iamb (left) and the trochee (right).

Serial number of pattern	IAMB			TROCHEE		
	1st AEP	2nd AEP	3rd AEP	1st AEP	2nd AEP	3rd AEP
1	168.8	194.4	175	166.3	180	186.9
2	165.6	175.6	165	173.8	185.6	175.6
3	160	191.9	166.3	161.9	165.6	186.9
4	155	176.3	147.5	163.1	164.4	163.8
Average	162.4	184.6	163.5	166.3	173.9	178.3

3. Relations between the psychophysical and electrophysiological data.

We did notice than the 300 ms interval produces an increase of the
P2 latencies as the 600 ms interval has no such clear effect. On the
other hand, in the both rhythmic patterns the 300 ms interval is more
over-estimated than the 600 ms interval. The increase of the P2 laten-
cies after 300 ms and the larger relative error on this interval repro-

duction have led us to investigate the relation between the N1 and P2 latencies and the reproduction performance for each of the 8 subjets. We then calculated the correlation coefficient between the mean N1 and P2 latencies of the 3 AEP of the 4 successive rhythmic patterns, and the relative error of the 300 and 600 ms intervals reproductions (Table 18 and 19).

Table 18 : Correlations between the mean N1 and P2 latencies and the relative error on the 300 and 600 ms intervals reproductions (IAMB), for 8 subjects.

	N1 latencies		P2 latencies	
	300 ms :	600 ms	300 ms :	600 ms
IAMB	:			:	
1st AEP	-.768 :	-.644	-.81 :	-.747
2nd AEP	-.892 :	-.647	.622 :	-.700
3rd AEP	-.644 :	-.382	:	-.276

Table 19 : Correlations between the mean N1 and P2 latencies and the relative error on the 600 and 300 ms intervals reproductions (TROCHEE), for 8 subjects.

	N1 latencies		P2 latencies	
	600 ms :	300 ms	600 ms :	300 ms
TROCHEE	:		:	
1st AEP	-.362 :	-.354	-.711 :	-.713
2nd AEP	-.543 :	-.581	-.529 :	-.494
3rd AEP	:	-.678	:	-.681

In the case of trochee, we have a negative relation between the P2 latency and the relative error (about 600 ms interval) in the first response. A similar relation was found in the last response with the relative error about the 300 ms interval. In the case of iamb, the same relation was found in the first response. A similar but non significative tendancy was found in all the other cases : all the calculated coefficients are negative, though some of them are not significative. We calculated the same correlation coefficients upon the N1 and P2 latencies of the 3 AEP of the only last rhythmic pattern : the correlations are then less significative than with the mean latencies, calculated upon

the 3 AEP of the 4 rhythmic patterns of the sequences. As for the single durations experiment, it seems that the reproduction performance may be related to the latency of the P2 component and, at a lower degree, to the latency of N1 in the first evoked response.

As precedently, we have selected the more under-estimating subject (F.P.) and the more over-estimating subject (M.E.). Comparing their respective results, we have found that the N1-P2 amplitudes are less varying along the stimulation sequences for M.E., and that the N1 and P2 latencies are longer for him than for F.P.. We can notice that F.P. under-estimates the durations in the cadences and the rhythmes experiments, and M.E. tends to over-estimate the durations in the both experiments (the cadences experiment AEP were discarded because too much artefacted).

The results presented here show a general tendency to longer reproduced durations related with shorter N1 and P2 latencies. This relation may reflect to some degree individual psychophysiological abilities, as information processing quickness or "intellectual quotient" (CALLAWAY, 1975). Thus, the P2 latency of the first AEP of each pattern could constitute a sign of the ability of the subject to reproduce the durations, before the following stimulations. This sign could be disturbed by the stimulation repetition, and so we could explain the low correlation between the last AEP components latencies and the reproduction performances. Other factors may influence the N1 and P2 latencies, as the subject's attention level. So, in a duration reproduction experiment, the response of the subject would be submitted to his level of attention at the beginning of the interval listening. As the stimuli sequences are almost regularly delivered by the experimenter, the subject may sometimes be a little disturbed by the stimulus arriving too soon after the last response. It seems that, due to the relative short interval between the subject's response and the next stimuli sequence, the attention of the subject can hardly recover the top level. On the other hand, the variations in N1 and P2 latencies may reflect to which degree the subject may re-direct his attention at the moment the first click of the pattern arrives.

VI. DISCUSSION.

The results concerning the durations reproduction tasks and the AEP will be discussed successively, then we will study the relation between them in the three experiments.

1. Durations reproduction performances.

The results of the reproduction tasks in the three experimentations are coherent with the results described in previous works. We did no-

tice an over-estimation of the short durations and an under-estimation of the long ones. These variations differ noticeably between the experimental situations : we found greater relative errors for the 300, 600 and 1200 ms durations when they were presented in single intervals than in cadences experiment. In the same way, we found greater variability of the reproduced durations in the case of single intervals.

The rhythms reproduction experiment has given some intermediate results. The 300 ms interval has been reproduced with a mean relative error and a variability of the reproductions smaller than in the two other experiments. For the 600 ms interval, the mean relative error is smaller than in the single intervals experiment, but larger than in the cadences experiment; we can notice some important variations between subjects. The variability of the 300 and 600 ms intervals reproductions are quite similar for the both rhythmic patterns.

The indifference interval found in the single intervals experiment is superior (1100 ms) to the ones found in the cadences experiment (645 ms). The first factor which may explain this difference is the repetition of the intervals in the cadences experiment. The second factor is that the scale of the durations to be reproduced is greater in the first experiment, from 150 to 2400 ms, then in the cadences experiment where the durations to be reproduced did extend from 300 to 1200 ms. The influence of the durations scale on the indifference interval has been explained by a "central tendency" (FRAISSE, 1948). In this view, the subject should concentrate on a mean duration, and the presented durations should be compared to this duration and their reproduction tend to come near the mean duration. This effect has been retrieved with durations from 15 to 35 sec (BOBKO et al., 1977). In the case of rhythmic patterns, we can notice than the relative errors obtained with the 300 and 600 ms intervals show important variations between the subjects, and the mean error obtained upon all the subjects is superior to zero with the both intervals.

2. Auditory evoked potentials.

For the AEP, our results are in general coherent with the published ones : we notice a decrease of the amplitudes as the intervals between the stimuli decrease. This decrease of the amplitude of the evoked responses recorded at the vertex of the cat has been found for the early AEP components, which correspond to the activity of the acoustic nerve, the cochlear nucleus, the superior olivary complex, the pre-olivary and lateral lemniscal nuclei, and the inferior colliculus (HUANG et BUCHWALD, 1978). In this study, the stimulation rates were more rapid than those we used, and so this influence of the stimulation rate cannot explain the decrease of the late components of the AEP that we have noticed.

Another point of discussion is the general shapes of the N1-P2 amplitudes curves in the cadences experiment. In most studies, the N1-P2 amplitudes describe a monotonously exponential decreasing function

(DAVIS et al., 1966; COOK, ELLINWOOD and WILSON, 1968; ZERLIN and DAVIS, 1967; etc.). This effect has been interpreted as an "habituation" of the evoked response (COOK, ELLINWOOD and WILSON, 1968). The degree of the amplitudes decrease was found to be a function of the stimulation rate and the duration of the stimulus (HUANG, 1981). A "dishabituation" of the evoked response can be obtained with a stimulus of different intensity or frequency (BUTLER, 1968), or with a "supplementary" stimulus occurring in a regular sequence (KLINKE et al., 1968): in this case, the different or supplementary stimulus produces a larger AEP, with a large positive component about 300 ms ("P300"). If we consider the N1-P2 amplitudes curves obtained in the cadences experiment, we can notice a slight increase of the amplitudes at the end of the sequences, which is in opposition with the previous results. This difference can be explained by a different experimental procedure: in our experiment, the subject had to reproduce the intervals between the clicks, and these clicks were all identical, as in the other cited experiments the subjects were not interested by the interstimulus interval, but by the stimulus characteristics (i.e. the pitch or the duration of the stimuli). It seems clear that in our cadences experiment the subject must take in account the whole interval between two successive clicks, but the processing of this information must be realized at the same moment following clicks are presented.

In experiments where subjects were asked to tap at first sound (FRAISSE, 1966), it has been found that settlement of beat-sound synchronization with cadences or rhythms is very fast, and simultaneity is already carried out on the third stimulus. In the present experiment, the subject did only reproduce the intervals after the stimulation sequence and we cannot know when the subject's response was already prepared. The conflict between the processing of the stored information and the perception of the presented stimuli may produce the observed decrease of the AEP: the amplitude of the AEP components are known to be influenced by the level of attention of the subject (FRUHSTORFER et al., 1970; SCHWENT et al., 1976; FORD et HILLYARD, 1981). We may formulate the hypothesis that, in the case of cadences, the attention of the subject is not constant during the whole stimulations sequences and that several mental processes are conducted successively:

- perception of the first interval;
- recognition of this interval by reference to an internal catalog of durations;
- preparation of a mental template of the duration;
- anticipation upon the arriving of following stimuli;
- comparison between this anticipation and the real arriving moment of the stimulus;
- eventually, correction of the mental template of the duration.

The execution of these processes needs time and a certain level of attention. So, the different intervals of the stimulation sequences may be taken in account by the subject not in the same way according to

their serial number. This idea could explain the increase of the N1-P2 amplitudes at the end of the stimulations sequences.

A sort of verification is brought by the results of the rhythms experiment. We have found a tendancy to larger N1-P2 amplitudes in response to the first click of each pattern of the stimulation sequences. The interval between this click and the preceeding one is 1200 ms and in the case of single intervals and cadences experiments we have never found so much important increase of N1-P2 amplitudes after 1200 ms intervals. Moreover, we have found the most significant difference between the first AEP of the pattern and the adjacent AEP at the level of the fourth presented pattern, that is to say at the end of the stimulation sequence. We can see here a similar evolution of the N1-P2 amplitudes, with a decrease of the N1-P2 amplitudes at the beginning of the sequences (due to an "habituation" of the AEP) followed by an increase of the amplitudes at the end of the sequences. This general U shaped curve is superposed to more "local" habituation decreases, inside the limits of each pattern, and between successive patterns some increases of N1-P2 amplitudes which may be related to a certain "re-direction" of the subject's attention. For the single intervals experiments AEP, the long-latency effect of the attention modifications cannot be clearly examined as in this case, the major part of the information processing should be realized "after" the end of the stimulation. In fact, we may consider that the probability for long intervals grows as time goes from the first click of each stimulation. As the subject has to reproduce the duration after a single presentation, his strategy should be different than in the case of the two other experiments where the durations presentation is repeated.

The study of the latencies brings less information upon internal mechanisms involved in durations reproduction tasks. We have found that the latencies of N1 and P2 tend to decrease for the second AEP in the single intervals experiment. In the cadences experiment, the mean N1 latencies tend to decrease as the intervals increase, as P2 latencies tend to increase for long intervals (900 and 1200 ms).

3. Relations between AEP and durations reproduction performances.

The first relation is the evidence that the errors in reproduced durations and the AEP amplitudes show similar curves : with short intervals between clicks, the absolute errors are greater and the N1-P2 amplitudes smaller than with long intervals. This relation has been found in the three experiments. But the interpretation of this relation is not so clear : a direct relation between the AEP amplitudes and the "perception of time" must be more closely observed.

A first consideration is that the decrease of the AEP amplitudes with short intervals has been found in experiments not involving the time perception, except if we consider that the subject waits for the next stimulus. An other fact is that the Vierordt's law has been verified with very long intervals (BOBKO et al., 1977), as with these inter-

vals (from 15 to 35 sec) the AEP show no amplitudes decrease (DAVIS et al., 1966). It is possible that, with short intervals, the decrease of the AEP amplitudes may constitute an indication of the subjective error in time perception, but we did not find a relation between the AEP amplitudes decreases and the reproduced durations across the subjects. In single durations experiment, we have found that the two successive AEP merge and cannot be easily distinguished, and on the other hand, this interval did appear too much brief for the subjects to reproduce it. In fact, the subjects tried only to produce the shortest interval they could without any consideration about the precision of reproduction.

Considering the N1 and P2 latencies, the results interpretation is a little more productive. For the AEP obtained in the rhythms experiment, we have found a negative relation between the P2 latencies and the relative errors in the reproduced durations: the smaller relative errors were related to the longer P2 latencies of the first AEP of the rhythmic pattern. This relation between the latencies and the reproduction performance has not been retrieved in the other experiments.

VI. CONCLUSIONS.

The three experiments reported here investigate the auditory evoked responses during durations reproduction tasks. The results obtained here show that the interval between two successive clicks is not the only factor influencing the auditory potential evoked by the second click. This interval has been found in other experiments to be responsible of a decrease of the AEP amplitudes and, in some cases, latencies when it decreases under 10 seconds. With stimuli presented in cadences, the AEP amplitudes showed a monotonuous negative exponential decrease, along the stimulation sequences and from trials to trials when the subject had to detect target stimuli (DONALD and YOUNG, 1982). In our experiment where subject had to reproduce the intervals between clicks, we found that AEP amplitudes defined a non-monotonuous decreasing curve for the different cadences.

In the same way, with rhythmic patterns the AEP showed contradictory tendancies : a 1200 ms interval (not taken in account by subject and not reproduced in this experiment) was followed by a N1-P2 amplitude increase. In the two first experiments (where this 1200 ms interval was reproduced) it was followed by a decrease of the N1-P2 amplitude. The effect on the N1 and P2 latencies was to some degree equivalent : we found shorter N1 and P2 latencies after this 1200 ms interval in rhythms experiment, as in the two other experiments these latencies tended to increase. It seems that this difference is due to a different context : when the subject can "ignore" an interval, this interval is followed by quite not changed AEP, and when this interval is taken in account, the following AEP is decreased. This decrease of the AEP may reflect the processing of informations corresponding to the perception of time by

the subject. Anyway, as we have found some correlations between the P2 latencies and the reproduction performances, it is possible that the late components latencies are related to the frequency of an "internal clock" involved in time perception. This theory, though still not proved upon anatomical research, could explain the inter-individual differences in reproduction performances. In this case, the evolution of the AEP characteristics in such our experiments could be due to many factors : the stimulation rate, the stimulation type (single intervals, cadences, etc.), the repetition of stimulation sequences, the subject's attitude, the peculiar capabilities of the subject and the physiological characteristics of his central nervous system. This interpretation needs to be verified by experiments upon other electrophysiological re-cordings, involving in example the motor potentials recorded during the duration reproduction, heart rate, reaction time.

VII. LITERATURE CITED.

ABRAHAM F.D., MARSH J.T. : Amplitude of evoked potentials as a function
             of slow presenting rates of repetitive auditory stimulation.
             Exper. Neurol., 1966, 14, 187-198.

ALLEN D. : Spatial summation in the evoked cortical response to
             auditory stimuli.
             Perception & Psychophysics, 1968, 4 (6), 355-356.

BOBKO D.J., SCHIFFMAN H.R., CASTINO R.J., CHIAPPETTA W. : Contextual
             effects in duration experience.
             Amer. J. Psychol., 1977, 90 (4), 577-586.

BOTTE M.-C. : Les réponses évoquées auditives.
             J. Psychol., 1979, 4, 381-402.

BUTLER R.A. : Effects of changes in stimulus frequency and intensity on
             habituation of the human vertex potential.
             J. Acoust. Soc. Amer., 1968, 44 (4), 945-950.

BUTLER R.A. : The cumulative effects of different stimulus repetition
             rates on the auditory evoked response in man.
             Electroenc. clin. Neurophysiol., 1973, 35, 337-345.

BUTLER R.A., KEIDEL W.D., SPREND M. : An investigation of the human
             cortical evoked potential under conditions of monaural and
             binaural stimulation.
             Acta oto-laryng., 1969, 68, 317-326.

BUTLER R.A., SPRENG M., KEIDEL W.D. : Stimulus repetition rate factors
             which influence the auditory evoked potential in man.
             Psychophysiology, 1969, 5, 665-672.

CALLAWAY E. : Brain potentials and cognitive potentials.
             in : PRESCOTT, READ, COURSIN : Brain function and malnutri-
                 tion : Neuropsychological methods of assessment.
                 J. Wiley and Sons, 1975.

COOK J.D., ELLINWOOD E.H., WILSON W.P. : Auditory habituation at primary
             cortex as a function of stimulus rate.
             Exper. Neurol., 1968, 21, 167-175.

DAVIS H., MAST T., YOSHIE N., ZERLIN S. : The slow response of the human
             cortex to auditory stimuli : recovery process.
             Electroenc. clin. Neurophysiol., 1966, 21, 105-113.

DONALD M.W., YOUNG M.J. : A time-course analysis of attentional tuning
             of the auditory evoked response.
             Exp. Brain Res., 1982, 46, 357-367.

FITZGERALD P.G., PICTON T.W. : Temporal and sequential probability in
        evoked potentials studies.
        Canad. J. Psychol., 1981, 35 (2), 188-200.

FORD J.M., HILLYARD S.A. : Event-related potentials (ERPs) to
        interruptions of a steady rhythm.
        Psychophysiology, 1981, 18 (3), 322-330.

FRAISSE P. : Les erreurs constantes dans la reproduction de courts
        intervalles temporels.
        Arch. de Psychol., 1948, 32, 161-176.

FRAISSE P. : L'anticipation de stimulus rythmiques : vitesse
        d'établissement et précision de la
        synchronisation.
        Année Psychol., 1966, 1, 15-36.

FRAISSE P. : Psychologie du Temps, P.U.F., 1967.

FRUHSTORFER H., SOVERI P., JARVILEHTO T. : Short-term habituation of
        the auditory evoked response in man.
        Electroenc. clin. Neurophysiol., 1970, 28, 153-161.

HORVATH R.S. : Variability of cortical auditory evoked response.
        J. Neurophysiol., 1969, 32 (6), 1056-1063.

HUANG C.-M. : Time constant of acoustic adaptation.
        Electroenc. clin. Neurophysiol., 1981, 52, 394-399.

HUANG C.M., BUCHWALD J.S. : Factors that affect the amplitudes and
        latencies of the vertex short latency acoustic responses
        in the cat.
        Electroenc. clin. Neurophysiol., 1978, 44, 179-186.

JASPER H.H. : The ten-twenty electrode system of the International
        Federation. Report of the Committee on methods of clinical
        examination in Electroencephalography (1957).
        Electroenc. clin. Neurophysiol., 1958, 10, 370-375.

KLINKE R., FRUHSTORFER H., FINKENZELLER P. : Evoked responses as a
        function of external and stored information.
        Electroenc. clin. Neurophysiol., 1968, 25, 119-122.

LESEVRE N. : Chronotopographical analysis of the human evoked potential
        in relation to the visual field (Data from normal individuals
        and hemianoptic patients).
        Ann. N.Y. Acad. Sci., 1982, 388, 156-182.

MACAR F. : Le Temps, perspectives psychophysiologiques, Ed. P. Mardaga,
        Bruxelles, 1980.

OHMAN A., LADER M. : Selective attention and "habituation" of the
        auditory averaged evoked response in humans.

Physiol. and behav., 1972, 8 (1), 79-85.

PICTON W.T., HILLYARD S.A., KRAUSZ H.I., GALAMBOS R. : Human auditory
            potentials. I: Evaluation of components.
            Electroenc. clin. Neurophysiol., 1974a, 36, 179-190.

PICTON W.T., HILLYARD S.A. : Human auditory evoked potentials.
            II: Effects of attention.
            Electroenc. clin. Neurophysiol., 1974b, 36, 191-199.

RITTER W., VAUGHAN Jr H.G., COSTA L.D. : Orienting and habituation to
            auditory stimuli : a study of short term changes in averaged
            evoked responses.
            Electroenc. clin. Neurophysiol., 1968, 25, 550-556.

ROTH W.T., KRAINZ P.L., FORD J.M., TINKLENBERG J.R., ROTHBART R.M.,
            KOPELL B.S.: Parameters of temporal recovery of the human
            auditory evoked potential.
            Electroenc. clin. Neurophysiol., 1976, 40, 623-632.

SCHWENT V.L., HILLYARD S.A., GALAMBOS R. : Selective attention and the
            auditory vertex potential : I. Effects of stimulus delivery
            rate.
            Electroenc. clin. Neurophysiol., 1976, 40, 604-614.

WASTELL D.G., KLEINMAN D. : Fast habituation of the late components of
            the visual evoked potential in man.
            Physiol. and Behav., 1980, 25, 93-97.

WEBSTER W.R. : The effect of repetitive stimulation on auditory evoked
            potentials.
            Electroenc. clin. Neurophysiol., 1971, 30, 318-330.

WILKINSON R.T., MORLOCK H.C. : Auditory evoked response and reaction
            time.
            Electroenc. clin. Neurophysiol., 1967, 23, 50-56.

ZERLIN S., DAVIS H. : The variability of single evoked vertex potentials
            in man.
            Electroenc. clin. Neurophysiol., 1967, 23, 468-472.

END

DATE

FILMED

DTIC

10-88